HORMONE AND HEMISPHERICITY HYPOTHESES REGARDING COGNITIVE SEX DIFFERENCES: POSSIBLE FUTURE EXPLANATORY POWER, BUT CURRENT EMPIRICAL CHAOS

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ABSTRACT: Two general hypotheses regarding the possible basis of cognitive sex differences posit sex steroid hormone differences and differences in hemispheric specialization characteristics as responsible. This article reviews (1) a limited segment of the literature regarding sex steroid influences, namely, that dealing with "activating" influences; and (2) some data suggesting that dextral women who are positive for familial sinistrality could be a group who contribute heavily to the mean sex difference in spatial ability. The general conclusion of these reviews is that despite the promise of some future integration of hormone and hemispheric specialization hypotheses and understanding of how they might relate to cognitive sex differences, present data are highly inconsistent.

There are well-established sex differences in tested cognitive skills, clearest on visuo-spatial tests, and particularly on those tests requiring mental rotation operations (Halpern 1986; McGee 1979). That spatial ability differences may, in fact, underlie other cognitive sex differences is suggested by findings that sex differences in mathematics scores of normal subjects evaporated when visuo-spatial test scores were used as a covariate (Casey, Nuttall, Harwood, Pezaris, & Benbow 1994; Hyde, Geiringer, & Yen 1975). Major reviews (Halpern 1986; Harris 1981; Maccoby &

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Jacklin 1974) have concluded that sex differences are not wholly explicable in terms of socialization experiences.

Two non-psychosocial hypotheses as to the basis of sex differences in abilities are that they are due, in some yet to be discovered way, to sex hormone influences or to sex differences in "hemisphericity," i.e., in the lateral specializations of the cortex for the cognitive processing of verbal and spatial material. Further, Geschwind and Galaburda (1985) have suggested that brain-organizing influences of testosterone may be responsible for hemispheric specialization characteristics.

Even in spatial ability, sex differences are far from absolute. There is great overlap between the sexes and the question comes down to "Are there subgroups of women and/or men who are responsible for the overall difference in mean scores?" The relevant array of studies bearing on this question is too large to permit a comprehensive review here. Consequently, I have chosen to provide, instead, (1) a limited and selective review of studies of cognitive abilities (mainly spatial) and sex steroid hormones (mostly concurrent) in subjects with presumably normal endocrine histories; and (2) a narrow consideration of discrepant and puzzling findings regarding possible "responsible-for-the-difference" subgroups of men or women in terms of their "anomalous dominance" characteristics. The main conclusion of this review will be that, to a disconcerting degree, whatever relationships are found in some studies, the relationships often are found to be absent or reversed in other studies.

SEX STEROID HORMONES AND ABILITIES

COGNITIVE ABILITIES AND SECONDARY SEX CHARACTERISTICS

Broverman, Broverman, Vogel, and Palmer (1964) proposed that females were superior to males in automated (fluent verbal or motor production) abilities, but inferior in perceptual restructuring (typically spatial) abilities. They believed female/male differences in abilities reflected differential potencies of estrogen and testosterone for inhibiting monoamine oxidase (MAO). Inhibition of MAO would result in higher effective levels of norepinephrine (and other catecholamines). Citing evidence that estrogen was a more powerful inhibitor of MAO than testosterone, they postulated that women were more neurally "activated" than men. Adrenergic activation was hypothesized to facilitate automated task performances, but to interfere with perceptual restructuring task performances because restructuring tasks required "inhibition" of initial response tendencies while the solutions were being worked out.

Klaiber, Broverman, and Kobayashi (1967) tested 115 college males on two automatized tasks (naming and reading speed of objects and color names, respectively) and two perceptual restructuring tasks (WAIS Block Design and Witkin Embedded Figures). They measured urinary 17-ketosteroids (a crude measure of androgens), MAO activity in blood plasma, and a variety of presumably sex

steroid-influenced "anthropometric" variables such as pubic hair distribution, chest circumference, right biceps size, height and weight, and leg length. Significant relationships were found between 17-ketosteroid levels and Block Design ($r = -.32$, $p < .05$) and between mean MAO levels and speed of name reading ($r = -.62$), but other correlations, though mostly in the directions predicted, were nonsignificant. Masculinity of pubic hair distribution and other supposed indices of androgen effects generally correlated positively with automated task performances and negatively with the Block Design and Embedded Figures scores. Finally, mean MAO activity was negatively related to all of the anthropometric measures of androgenization except height. The authors concluded: "Therefore, the overall results of the study seem to suggest that androgens inhibit brain MAO activity which, in turn, results in an elevation of brain norepinephrine levels. Increased levels of brain norepinephrine are then thought to induce a heightened state of behavioral reactivity thus facilitating the automatization of behavior" (1967, p. 334).

Subsequently, Petersen (1976), studying adolescents, found a negative relationship in males, and a positive relationship in females, between masculinity of secondary sex characteristics and WAIS Block Design plus Primary Mental Abilities Space Test. Berenbaum and Resnick (1982), however, also studying adolescents, failed to find significant relationships between physical androgyny and abilities in either sex. Results from these three studies of secondary sex characteristics give only weak support to the hypothesis that sexual "androgyny" is favorable to spatial ability. Furthermore, the androgyny hypothesis cannot provide the answer to sex differences in abilities unless one assumes that androgyny is more common in males than females.

COGNITIVE ABILITIES AND MEASURED SEX STEROID LEVELS

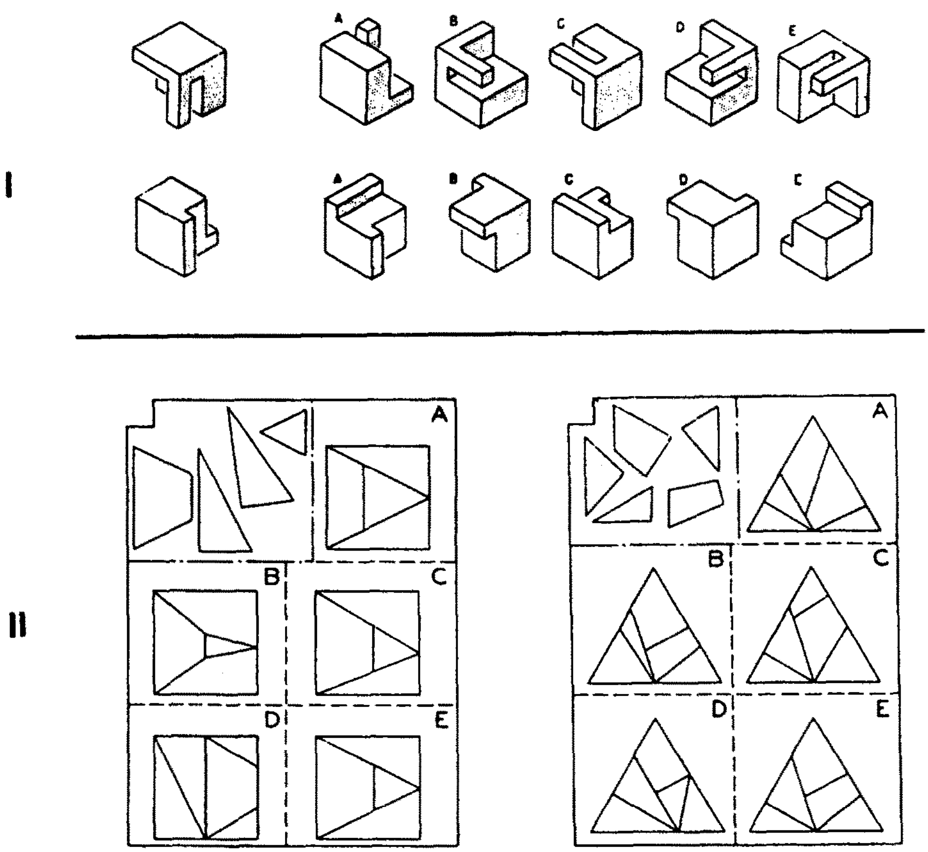
A number of studies have sought to assess the relationship of circulating hormones to abilities more directly. Shute, Pellegrino, Hubert, and Reynolds (1983) employed a radioimmunoassay (RIA) for testosterone, but the values it yielded were too high to represent testosterone alone. Consequently, they spoke of "androgen" in discussing their results. Two studies were reported. In the first they found that the mean of six spatial tests from the French Reference Kit for Cognitive Factors (French, Ekstrom, & Price 1963) yielded significant linear, quadratic, and cubic trends for males. The scatterplot shows that, in general, low androgens were associated with high spatial scores. For females, no trends were significant, with the linear trend (apparently the largest) showing a non-significant positive relationship ($r = +.12$). In a second study they contrasted the performances of the six highest and six lowest androgen level subjects of each sex, out of an original sample of 18 females and 15 males. They found that low androgen level was associated with significantly higher performances by men and lower performances by women on the Revised Minnesota Paper Form Board (Likert & Quasha 1970), but not on the other two spatial tasks administered. They interpreted the results as showing that low androgen males and high androgen females possess the better spatial abilities.

Gordon and Lee (1986) tested 32 men and 30 women on the visuospatial and verbal/sequential subtests of Gordon's Cognitive Laterality Battery. They were tested twice, one week apart. All subjects had an in-dwelling catheter "locked" in a vein of the left arm via which a total of 11 blood samples were collected during each testing session. Blood samples were consolidated and tests for testosterone were conducted. For the first testing session data there was only one significant correlation of testosterone with the 10 subtests administered. This was a positive correlation ($r = +.54$) between testosterone and Orientation, the only mental rotation task in the battery. For the second session, however, this correlation was close to zero. For women, testosterone was not measured, but estrogen and progesterone were. Estrogen was negatively correlated with the composite verbal/sequential tests score ($r = -.31$), but again, for the first session only.

McKeever, Rich, Deyo, and Conner (1987) studied 38 sinistral and 45 dextral college students. Subjects took the Minnesota Paper Form Board, the Stafford Identical Blocks Test (Stafford 1961), the Shipley Hartford Vocabulary Test (Shipley 1940), and a brief test of word fluency which required writing as many words starting with the letter "G" as possible in two minutes. The Minnesota Paper Form Board is an example of a spatial relations test while the Stafford Identical Blocks Test is a spatial visualization test which requires mental rotation (see Figure 1). Blood samples were taken immediately upon completion of the two spatial tests, which were always completed at 10:50 AM. It is necessary to take blood at a set time because testosterone levels vary over the course of the day, with highest levels in the morning. A sensitive and specific test for testosterone was performed. For the Stafford Identical Blocks Test, it was found that males significantly outperformed females, and dextrals outperformed sinistrals, replicating earlier findings (McKeever 1986). The effect of sex approached significance for the Minnesota Paper Form Board ($p < .07$). There were no significant sex, handedness, or interactional effects for the other tests. Most importantly, there was no association of testosterone with any test scores. The testosterone levels of females were so uniformly low as to negate any possibility of correlation with other variables. It was concluded that testosterone could not have been the androgen responsible for the androgen-Minnesota Paper Form Board relationship reported for men by Shute et al. (1983).

Christiansen and Knussman (1987) tested 110 young men on six fluent production and six spatial tests, the latter being Block Design, Embedded Figures number correct, Embedded Figures total time, the Leistungsprufsystem subtest for Field Dependence-independence, and two additional Leistungsprufsystem spatial subtests. Subjects took the same tests in two sessions, 10 to 20 days apart. Assays were conducted for plasma testosterone, dihydrotestosterone, and salivary (free) testosterone. Plasma testosterone showed significant negative relationships with two of the six fluent production tasks and significant *positive* relationships with four of the six spatial tasks; dihyrdotestosterone showed non-significant negative relationships to five of the six verbal tasks, and significant positive correlations to two of the six spatial tasks; salivary testosterone showed one significant negative correlation to the verbal tests and one significant positive correlation to the spatial tests.

FIGURE 1
Sample items from the Stafford Identical Blocks Test (I) and the Minnesota Paper Form Board Test (II). On the former subject chooses the item (A–E) which, though rotated to a different perspective, is the same shape as the standard on the left; on the latter subjects chooses figure (A–E) that could be constructed from the components shown.



Finally, the ratio dihydrotestosterone to plasma testosterone (DHT/T) showed significant negative relationships to two of the spatial tasks, i.e., the lower dihydrotestosterone was in relation to testosterone, the better the spatial task performances. It should be noted that all significant correlations were low (.22 to .26). These data are quite opposite what would be expected for androgen-ability relationships in men according to Klaiber et al. (1967) and Shute et al. (1983) who found *negative* correlations between measures of androgens and spatial abilities. Christiansen and Knussman (1987) concluded that circulating androgens are positively related to spatial ability and negatively related to fluent production ability in men. They argued that the negative relationships between testosterone and spatial ability in

men implied by secondary sex characteristics-abilities relationships reported by Klaiber et al. (1967) and Petersen (1976) were based on out-dated and erroneous ideas about the relationships between secondary sex characteristics and testosterone. They suggested, in other words, that the higher spatial ability males regarded as "less masculinized" by Klaiber et al. (1967) and Petersen (1976) were, in fact, the more masculinized males.

McKeever and Deyo (1990) tested 58 male undergraduates on the same test battery used earlier (McKeever et al. 1987), but measured dihydrotestosterone in addition to testosterone. Neither single measure related significantly to ability measures. The ratio of dihydrotestosterone to testosterone (DHT/T), however, was related to Minnesota Paper Form Board performances ($rho = -.27, p = .041$), as in the Christiansen and Knussman (1987) data. These results, then, showed a relationship of DHT/T to spatial task performances as found by Christiansen and Knussman (1987), but the deviation scores suggested that a curvilinear relationship might exist, such that those men whose DHT/T ratios are substantially below or above the usual ratio of about .33 may have the best performance.

Christiansen (1993) again found small but significant (r =.20 to .34) positive correlations between some spatial ability measures and plasma testosterone, as well as salivary testosterone and dihydrotestosterone, in a sample of 114 African Bushmen tested with the Portable Rod and Frame Test, the African Embedded Figures Test, and the Witelson Dichaptic Stimulation Test (1974). Dihydrotestosterone showed a significant *positive* correlation with a test of rapid object naming and a significant negative correlation with the degree of inferred right hemisphere superiority for the spatial Witelson Dichaptic Test. Estradiol was also assayed and did not relate directly to cognitive test results.

Gouchie and Kimura (1991) administered brief Paper Folding, Mental Rotations, Mathematics Aptitude, Identical Pictures, Finding A's, Tongue Twister, and Advanced Vocabulary tests to 66 men and 70 women. Testosterone was measured in saliva by assay. A MANOVA showed a main effect of sex, reportedly due to the superiority of males on math and spatial tests. No other tests yielded sex differences. A median split was effected on testosterone levels within each sex, yielding four groups. Tests of the prediction that low testosterone men would perform better than high testosterone men on the individual math and spatial tests were *not* supported. Standard scores were computed to allow grouping of math, mental rotation, and paper folding as a "male superior" composite and the other tests as a "non-male superior" composite. Low testosterone males were found to be significantly superior to high testosterone males and high testosterone females were significantly superior to low testosterone females on the male composite. No within-sex testosterone level effects were seen on the non-male composite. The investigators concluded that the pattern seen on the composites was consistent with the curvilinear hypothesis of the relationship between androgens and spatial ability, across sexes, that has been termed the androgyny hypothesis.

Although women were not included in many of the above studies there are a group of studies that focussed exclusively on women.

MENSTRUAL CYCLE AND HORMONE MANIPULATION STUDIES OF WOMEN

A number of studies examined the relationship of spatial ability to menstrual cycle phase. Komnenich, Lane, Dickey, and Stone (1978) found women's performances on a color naming task (but not color reading or Digit Symbol) to be superior when they were tested at the high estrogen (pre-ovulatory) point of the cycle. This cycle phase yielded the lowest performances on Embedded Figures. Measured estradiol was positively related to a composite automatization task score.

Three additional carefully executed studies have also assessed possible relationships of menstrual cycle phase to test performances. Hampson and Kimura (1988) studied 34 normal cycling young women (mean age 24.7). Subjects were tested twice, once on days 3 to 5 of menses and again on a day targeted to be seven days prior to menstruation (mid-luteal). The testing order was counterbalanced across phases. Estrogen and progesterone are both normally quite low during menses and high during the mid-luteal period. Results showed that performance on the Portable Rod and Frame Test was significantly better during menses than during mid-luteal testing, while Finger Tapping and Purdue Pegboard (assembly measure) and three of six speed measures on Kimura's Manual Sequence Box were significantly better at mid-luteal testing. It was inferred that high levels of endogenous steroids are facilitative of speeded manual coordination but unfavorable for perceptual-spatial ability.

Hampson (1990a) tested 45 women for whom menstrual cycle phase was determined as in the Hampson and Kimura (1988) study. She administered an expanded set of tests, including batteries for spatial, perceptual speed, verbal fluency, articulation, manual speed, and deductive reasoning abilities. For the first testing session data, spatial ability and deductive reasoning were significantly better at the menstrual than at the mid-luteal testing; and articulation scores were significantly better during the mid-luteal than menstrual phase. The spatial ability effect was non-significant in the second testing session data, suggesting, perhaps that repeated testing can change hormone-performance relationships. The mid-luteal phase was associated with higher verbal-articulatory skills, fine motor skills, verbal fluency, and perceptual speed. Hampson concluded that these observed effects reflected the influences of mid-luteal elevations of estrogen and progesterone levels, while the observed decline in spatial test performance during the first session provided limited support for a negative effect of higher estrogen and progesterone levels on spatial ability.

Hampson (1990b) followed this study with a similar one, using the same batteries of tests, but this time she tested subjects in the menstrual phase and the late follicular phase. The strategy of contrasting menstrual with late follicular (pre-ovulatory high estrogen, low progesterone phase) was to clarify whether the results previously obtained reflected estrogen or progesterone effects. Late follicular phase testing was targeted for 16 days prior to the expected dates of next menstruations, with actual menstruation dates confirmed by subjects. Assays for estrogen and for progesterone were used to confirm the hormonal distinctiveness of the phases and those who did not conform to the expected hormone levels were excluded. However, 15 of the

retained 50 subjects were not tested at all for hormone levels. Results showed significantly better spatial performance during the menstrual phase, but deductive reasoning showed no influence of phase. Of the speeded tasks, only the articulatory and manual speed tasks showed differences, performances being significantly better during the pre-ovulatory phase. Hampson concluded that these effects were due to differences between the phases in estrogen levels, i.e., that estrogen is positively associated with enhanced speeded task performances and negatively associated with spatial task performances.

Unfortunately for clarity, Gordon and Lee (1986, 1993) assayed estrogen and progesterone from women at various points of their menstrual cycle and found *no* relationships to performances on Gordon's (1986) Cognitive Laterality Battery (CLB). The CLB incorporates two types of tasks, verbal-sequential, which clearly are fluent production tasks, and visuo-spatial tasks, including point localization, mental rotation, and spatial visualization tasks. Gordon and Lee (1993) speculated that reports of relationships of test performances to cycle phase or hormones might represent only the more publishable (i.e., positive) findings of researchers.

Van Goozen, Cohen-Kettenis, Gooren, Frijda, and Van De Poll (1994) reported a poorly controlled but very interesting study of 22 female-to-male transsexuals tested prior to and three months after being put on testosterone supplements, all prior to sex-reassignment surgery. Patients had normal menstrual cycles and typical female levels of gonadotrophins, testosterone, estradiol, and prolactin prior to treatment. Results showed a significant pre- to post-testosterone administration gain (slightly more than half a standard deviation) on the Rotated Figures Test (Ekstrom et al. 1976), and significant *declines* in verbal fluency as measured by the Word Production and Sentence Production subtests of Gordon's Cognitive Laterality Battery. Despite the fact that there was no control over practice effects, the significant decrements on the fluency test suggest the changes in cognitive performance were not due simply to practice.

Finally, Varney et al. (1993) gave an extensive test battery to women who were being treated for infertility. As part of the treatment program they were administered leuprolide acetate, which induces a profound hypoestrogenism during one phase of the treatment. The study was initiated in response to spontaneous complaints of previous program patients about poor memory and clumsiness. Subjects were tested before, during, and after the hypoestrogenism on ten tests (fine motor coordination, gross motor coordination, Benton's Controlled Oral Word Association, paired associate learning, verbal recall, Benton's Judgement of Line Orientation, tactile two-point discrimination, digit sequence learning, and Digit Symbol and Digit Span from the WAIS-R). Surprisingly, only two tests showed significant effects (reductions) during hypoestrogenism—two point discrimination and Digit Sequence Learning. The most important finding, however, was that individual subjects varied widely in responses to hypoestrogenism, with two of the 18 subjects manifesting such symptoms as memory gaps, spells of aphasia, confusion, and visual, auditory, olfactory or somatosensory illusions. A significant number of women, more than half in some cases, showed memory declines while, at the same time, many showed offsetting practice effect gains from the baseline testing through

TABLE 1
Relationship of Measured or Inferred Sex Steroids with Automated or Spatial Test Performances (E = Estrogens, P = Progesterone, T = Testosterone, DHT = Dihydrotestosterone, A = Androgens, and M = Masculinity

	Studies of Female Subjects	
Investigators	*Automated Tests*	*Spatial Tests*
Petersen 1976	No Relationship	+ with M
Komnenich et al. 1978	+ with E	Inferred - with E
Shute et al. 1983	Not Assessed	+ with A[@]
Gordon and Lee 1986	- with E[*]	No Relationship
Kimura and Hampson 1988	Inferred + with E and/or P	Inferred - with E and/or P
Hampson 1990a	Inferred + with E and/or P	Inferred - with E and/or P[*]
Hampson 1990b	Inferred + with E	Inferred - with E
Gouchie and Kimura 1991	No Relationship	+ with T
Gordon and Lee 1993	No Relationship	No Relationship
Varney et al. 1993	Not Related to E	Not Related to E
Van Goozen et al. 1994	- with T	+ with T
	Studies of Male Subjects	
Klaiber et al. 1967	+ with M	- with M
Petersen 1976	+ with M	- with M
Shute et al. 1983	Not Assessed	+ with A
Gordon and Lee	Not Related to T	+ with T[*]
McKeever et al. 1987	Not Related to T	Not Related to T
Christiansen and Knussman 1987	- with T	+ with T, DHT, and - with DHT/T
McKeever and Deyo 1990	Not Assessed	- with DHT/T
Christiansen 1993	- with T + with DHT	+ with T Not Related to DHT
Gouchie and Kimura 1991	Not Related to T	- with T

Notes: [*]effect only in first testing session
[@]effect in study 2 only

subsequent testings. In other words, sex steroids may be quite important for abilities in some persons, and quite unimportant in others.

Table 1 provides a summary of findings reviewed in this section.

HANDEDNESS, HEMISPHERIC SPECIALIZATION, AND COGNITIVE ABILITIES

Levy (1969) suggested that left handed individuals experience some enhancement of verbal functions through a greater bilateralization of language processes, but suffer a reciprocal deficit in spatial ability because of the "invasion" of the right hemisphere by language. McGlone (1980) suggested that females are less lateralized for language and spatial processing than males. Coupled with the view (Levy 1969)

that spatial ability is favored by strict lateralization and language abilities by a more bilateralized language organization, the hypothesis of greater bilateralization in women suggested that sex differences in cognitive abilities resulted from hemispheric specialization differences between sexes.

Geschwind and Galaburda (1985) proposed that left handedness is caused by exposure to "excessive testosterone" during fetal development and that this affects males more often than females because the fetal testes produce testosterone. Persons hypothetically exposed to excessive testosterone were proposed to possess "anomalous dominance" which favors "right hemisphere talents" such as spatial ability, music, and perhaps creativity. Markers for anomalous dominance were suggested to be left handedness, positive familial sinistrality (FS+), and immune or auto-immune disorders, and because of their greater testosterone exposure, males would be expected to show anomalous dominance more frequently. This model proposes, therefore, that the statistical male advantage in spatial ability reflects the more common exposure of males to excessive fetal testosterone. Thus, while Levy postulated lower spatial ability in sinistrals and women, Geschwind and Galaburda postulated lower spatial ability in dextrals and women.

Rounding out all possibilities, Annett (1985) proposed a theory of language laterlization (1985) that suggests that the *weakly* right handed should have better spatial and other abilities than the left handed or the strongly right handed. Sex is worked into the mix by Annett's proposition that the right shift gene that favors left hemisphere speech and dextrality is "more strongly expressed" in females.

Finally, Bakan (1971) proposed that right handedness is a species specific human trait and that deviations from it reflect pathological or non-normative disruptions of the universal pattern for right handedness. Bakan (e.g., Bakan, Reid, & Dibb 1973) views FS+ status as a marker for familial vulnerability to non-optimal pregnancy and birth events. While Bakan has made no specific pronouncements regarding ability correlates of left handedness, it seems safe to infer that left handers would not be cognitively favored by the disrupting or damaging left hemisphere events Bakan hypothesizes as the usual proximate causes of left handedness. There are no clear sex differences in abilities implied by Bakan's hypothesis.

There is a very extensive and conflicting literature regarding the question of whether or not there are spatial ability differences between left-handers and right-handers. This has been reviewed relatively recently (McKeever 1991; Lewis & Harris 1990). There is presently no definitive judgement that can be made on this question. I would like, instead, to review some of my own work which has suggested a tentative answer to the question "Is there an identifiable subgroup of males or females who might be responsible for the overall sex difference observed in visuospatial ability?" The most straightforward answer is "I don't know," but I can relate what we've found to date, noting, as well, that it does not necessarily agree with some of the findings of others.

In our studies of spatial ability we have employed mainly the Stafford Identical Blocks Test, but since 1987 have also routinely used the Minnesota Paper Form Board. Figure 1 shows examples of items from these tests. We have also employed the Shipley Hartford Vocabulary Test and word fluency tasks I described earlier, to

get brief measures of vocabulary and verbal fluency. The Stafford Identical Blocks Test is a 30-item spatial visualization test, quite difficult for most people. The Minnesota Paper Form Board is a 64-item spatial relations test. Our original reason for testing for spatial ability was Levy's hypothesis that left handers should have lower spatial ability because of their more frequent dedication of some right hemisphere space to language. In early studies we gave only the Stafford Identical Blocks Test, administered after the subject had completed a dichotic listening or tachistoscopic task.

Over the course of about six years the Stafford Identical Blocks Test was administered to both left and right handed, but mostly right handed, college subjects. The samples were labeled the 1976, 1978, 1980, and 1981 samples. Subjects were required to report the writing hand of their parents, siblings, and biologically related aunts and uncles. They were told to check with their parents regarding the handedness for writing of second degree relatives during a period at home or in any phone conversations with parents, and then to fill out the required form and mail it via campus mail. Each subject was then classified for familial sinistrality, with those having at least one first degree *or* two second degree left-handed relatives being designated as FS+. The overall performance of dextral subjects was evaluated comprehensively for the first time in 1982, and a report of the findings followed (McKeever, Seitz, Hoff, Marino, & Diehl 1983). Scores from each of the four subsamples were subjected to a two-factor ANOVA, with the factors being sex and FS. Main effects for sex were found in three of the four separate samples, with males scoring significantly higher in all but the smallest of the samples. There was no main effect of FS in any sample, but there was a sex by FS interaction in three of the four samples, with the same interactional pattern in the non-significant one. The analysis across all samples showed a highly significant main effect of sex ($p < 0.0004$) and a significant interaction of sex and FS ($p < 0.0004$). Interestingly, the FS– female performance on the Stafford Identical Blocks Test was not significantly different from that of FS– males, though it was inferior to that of FS+ males. The FS+ female performance was significantly inferior to both FS– and FS+ males. In short, the highly significant superiority of males over females in the sample as a whole was mainly due to the poor performance of FS+ females.

A subsequent study of 225 right handers and 134 left handers (McKeever 1986) revealed a significant sex difference on the Stafford Identical Blocks Test (males superior) and a significant handedness effect (dextrals superior). Once again, among dextral females the FS– scored significantly higher than FS+ females. There was no difference in the scores of FS– and FS+ males.

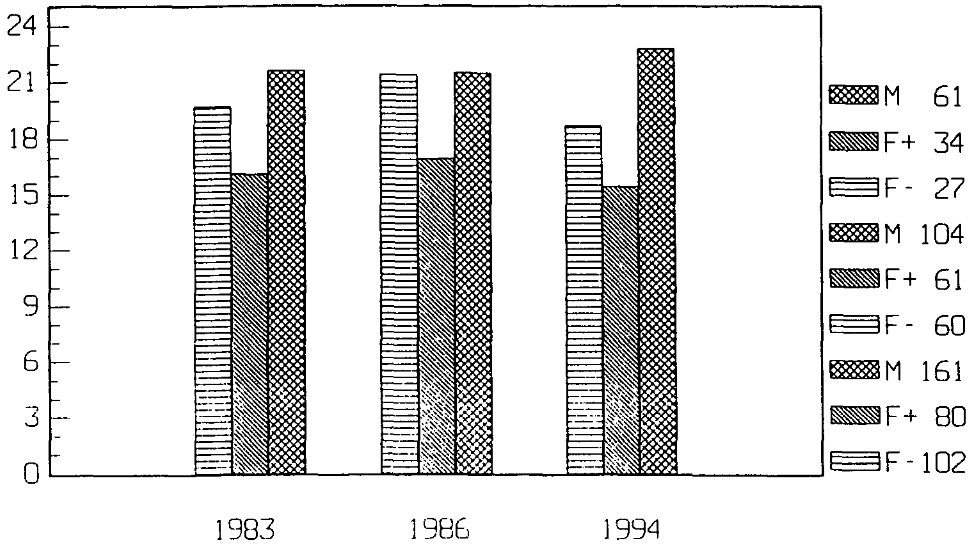
Results motivated a study of possible associations between handedness, plasma testosterone, and performances on the Stafford Identical Blocks Test, Minnesota Paper Form Board, Shipley Hartford Vocabulary Test, and verbal fluency test (McKeever et al. 1987). Subjects were 19 sinistral males, 19 sinistral females, 23 dextral females, and 22 dextral males. Results showed no differences in testosterone between handedness groups and no significant associations of testosterone to any of the cognitive measures. A three factor ANOVA (sex, handedness, FS) on each measure showed significant effects only on the Stafford Identical Blocks Test. These

were significant main effects of sex (males superior) and handedness (dextrals superior). The sex effect was short of significance on the Minnesota Paper Form Board, although the trend was for better male performance ($p < .07$). Although the sample was too small to lead one to expect a significant FS effect for right handed females, the means were, as in previous studies, higher for the FS– than the FS+ dextral women.

Subsequently, Rich and McKeever (1990), in a study of possible effects of Geschwind's and Galaburda's "markers" for anomalous dominance (handedness, FS, and history of immune disorder) on a verbal dichotic task, and on the four measures employed earlier, studied 64 sinistral and 64 dextral college students. Sex, handedness, FS, and immune disorder (ID) factors were perfectly counterbalanced. Immune disorders were mostly allergies, but regardless of type of immune disorder it was required that the disorder had been diagnosed and treated by a physician. Those in the non-immune disorder group had checked an immune disorder inventory category defined as "no reason to think I have ever had any of the disorders listed." The FS status in this study was based on first degree relatives only, as in the McKeever et al. (1987) study. Results showed a main effect of handedness on the verbal dichotic task (shown earlier in the McKeever 1986 study as well), significant effects of sex and of handedness on the Stafford Identical Blocks Test (males and dextrals superior), and a significant effect of handedness of the Minnesota Paper Form Board (dextrals superior). There was no sex difference on the form board. There were also sex effects on the vocabulary test (males superior) and verbal fluency (females superior). The most interesting, and essentially mysterious findings, were highly significant interactions of familial sinistrality and immune disorders on both spatial tasks, wherein subjects, regardless of sex or handedness factors, who were "minus" or "plus" for both the familial sinistrality and immune disorders factors were clearly better on the spatial tests than subjects who were "minus" for one factor and "plus" for the other. Because we are only now beginning a replication study of this effect I will not speculate on its meaning here. With only 16 FS– and 16 FS+ dextral females, it was not surprising that the difference, though favoring the FS– on the SIBT, was nonsignificant.

In a later analysis (McKeever & Rich 1994), we combined the two small samples of dextral females from the Rich and McKeever (1990) and McKeever et al. (1987) samples, including six additional women from the McKeever et al. (1987) study who were omitted from the original report because of loss of their blood samples during centrifuging of capillary tubes. This combined sample included 27 FS– and 34 FS+ women, who had been administered the same batteries. The difference in the Identical Blocks test scores for these FS– and FS+ dextral women approached significance, $F(1, 59) = 3.08$, $p < .081$), and when form board scores were used as a covariate, the FS– women showed significantly superior Identical Blocks test scores ($p < .033$). Figure 2 shows mean SIBT scores (maximum possible = 30) for FS– and FS+ females and for males obtained in the 1983 composite sample (McKeever et al. 1983), the 1986 sample (McKeever 1986), and the McKeever and Rich (1994) sample. These performances, by 175 dextral FS+ women, 189 dextral FS– women, and 326 dextral males, all generated from individual test administrations, argue strongly

FIGURE 2
Mean Stafford Identical Block Test Scores of FS– and FS+ Dextral Females and of Dextral Males in Three Samples (Right Margin Shows Ns)



that the FS+ dextral women are a group whose spatial visualization ability is inferior, on average, to that of males.

These differences emerged in our data very consistently over the years and we have never made much of them or had any definitive explanation of them. One could, of course, hypothesize that FS+ dextral females are less lateralized for language than FS– females, but we have consistently failed to find indications of language laterality differences between these groups on dichotic listening and verbal tachistoscopic tasks that discriminate handedness groups quite nicely. Bakan might suggest that since FS+ is a marker for non-optimal pregnancy and birth events, that perhaps the FS+ are left hemisphere damaged and that the right hemisphere has consequently been "invaded" by language, an explanation inherent in the Levy (1969) hypothesis. But such conditions should presumably apply to males as well, and FS– and FS+ dextral males do not differ on the SIBT nor in language lateralization in our studies. Another possibility, if one were to accept findings such as those of Hampson (1990a, 1990b), would be that perhaps FS+ women have menstrual cycles that are longer or different in some way that puts them in a "low spatial" phase for a greater period of time than occurs for FS– females. This is a testable hypothesis. Whatever the basis of the findings, dextral FS– female superiority over dextral FS+ females and the superiority of dextrals over sinistrals on the SIBT, have consistently emerged in our studies. Unfortunately, the exact opposite inference regarding spatial ability in FS– and FS+ dextral females has

been made by Casey and colleagues (e.g., Casey & Brabeck 1989, 1990), i.e., that FS+ dextral women are likely to possess higher spatial ability than FS– dextral women.

Although Casey and I have discussed this to some extent, its meaning has eluded us to date. There are many differences between our studies. First of all, Casey and colleagues have used the Vandenberg Test of Mental Rotation rather than the Stafford Identical Blocks Test, but an old study by Vandenberg and Kuse (1978) showed a substantial correlation between these tests ($r = +.69$); and Yeo and Cohen (1983) found, contrary to Casey and colleagues, in unselected college students, that dextral FS– females performed substantially better than dextral FS+ females on the Vandenberg Mental Rotation Test. Actually, Casey and colleagues have not found an "FS+ advantage" in straightforward testing of unselected FS– and FS+ dextral college women. In the Casey, Brabeck, and Ludlow (1986) study there was no effect of familial sinistrality in the initial testing, and the only FS+ women who showed an advantage over FS– women in the second testing were those in the group that received instructions in how to "mentally rotate" the test figures. In the Casey and Brabeck (1989) study, FS+ exceeded FS– subjects only among science majors, not among non-science majors.

We have not recruited subjects by major or by the amount of "spatial experiences" they have had. Additional differences include the fact that we have defined handedness of subjects and their relatives strictly in terms of writing hand and Casey and colleagues have used a criterion which requires subjects to fill out the Edinburgh Handedness Inventory as they think their relatives would. Further, Casey and colleagues have used only first degree relatives and our earlier studies used first and second degree relatives in defining FS. However, the McKeever and Rich (1994) analysis used only first degree relatives and the effect was still substantially present and significant when variance associated with spatial relations ability was removed from the spatial visualization variance. The view of Casey and colleagues that their obtained indications of spatial advantage of FS+ over FS– dextral women is predictable from Annett's (1985) theory and that the FS+ should have the Annett-hypothesized "heterozygote advantage" while the FS– should not is questionable.

Casey and colleagues have classified only those women with Laterality Quotients (LQ) on the Edinburgh Inventory of +40 and higher as their dextrals and have used familial sinistrality status to attempt to index the genotypes postulated by Annett's (1985) theory. They have assumed that FS+ versus FS– status differentiates subjects' genotypes, but Annett has advocated using asymmetries in hand skill (peg moving times) as the best approach to attempting to identify genotypes. If FS+ status adequately indexed genotype, one should expect dextral FS+ subjects to show a smaller manual performance asymmetry than shown by FS– subjects. We know of no evidence for this, and McKeever and VanDeventer (1977) found evidence against it—no differences between FS– and FS+ women or men in manual asymmetries on the Finger Tapping Test or Grooved Pegboard Test. Finally, by restricting their right handed subjects to those with laterality quotients of 40 or higher, it seems likely that the "dextrals" of Casey and colleagues, regardless of familial sinistrality status, would be predominantly homozygous dominants rather than the heterozygous subjects Annett hypothesizes to have the "heterozygote advantage" in abilities. Be

that as it may, Casey and colleagues have found some consistent FS effects in selected dextral females and, at least on the surface, they seem contrary to our findings. Harshman et al. (1983) found that reasoning ability moderated handedness by sex interactions, such that for high reasoners, left handed males showed reduced spatial ability relative to right handed males, while left handed females showed higher spatial ability relative to right handed females. For low reasoners, the exact opposite pattern obtained. Kimura and D'Amico (1989) found that left handed science students were superior to right handed science students in spatial ability, but among non-science students the left handers were inferior to right handers. Perhaps some unindexed moderator variable is responsible for the fact that the data of Casey and colleagues are telling them that FS+ dextral females are comparable to males in spatial ability, while our data tell us the FS– females are more likely comparable to males in spatial ability. Hopefully, further studies will resolve this.

SUMMARY AND CONCLUSIONS

The literature concerning the relationship of sex steroid hormone influences to sex differences in cognitive abilities is marked by many inconsistencies. The question of whether high or low androgens are favorable for spatial ability in men has yielded no consistent answer. Data showing testosterone (or "androgens" in Shute et al. 1983) favorable for spatial ability in women were obtained by Shute et al. (1983), Gouchie and Kimura (1991) and by Van Goozen et al. (1994), yet most of the menstrual cycle data suggests that spatial test performances are highest when estrogen and progesterone are lowest (during menses), while automated test performances are highest when estrogen and progesterone (and presumably testosterone, though unmeasured) are highest. In any case, the majority of menstrual cycle studies do suggest that the normal sex difference in tested spatial abilities could reflect the fact that, at any given point in time, the majority of women are in a lower spatial (non-menstrual) phase of their cycles. Studies employing a more comprehensive assessment of sex steroids are needed to clarify this picture.

With respect to hemispheric specialization as an explanation of sex differences in cognitive abilities, the data are similarly inconclusive. The hypothesis of sex differences in language lateralization, despite its popularity, is not definitively established. Our own studies (McKeever 1986; McKeever et al. 1987; Rich & McKeever 1990) do support Levy's hypothesis of inferior spatial abilities in unselected male and female college sinistrals, but some have found sinistrals, or one sex or the other of sinistrals, to be superior in spatial ability. Our data suggest that dextral FS+ women, despite a normal range of spatial visualization scores, have a mean that is approximately one-half a standard deviation below that of dextral FS– women, and could be responsible for the overall sex difference in spatial ability, but there is need for further replication.

This area of research remains fascinating. Recent studies suggesting possible handedness and cognitive ability pattern differences between heterosexual and homosexual persons (Lindesay 1987; McCormick & Witelson 1991; Holtzen 1994), and the Moffat and Hampson (1993) finding of systematic salivary testosterone differences between sinistrals and dextrals are most interesting. It seems almost a certainty that progress will be made in the general area. At the same time, the findings of Varney et al. (1993) suggest that the importance of sex steroids in ability patterns may be highly variable, important in some, and unimportant in other persons. The biochemical milieu conducive to specific cognitive skills may be diverse. The problem is probably one of inadequate subtyping of individuals. Additionally, little is currently known about the mechanisms of sex steroid effects on the neuropsychological substrate of abilities. Even when cognitive correlates of sex steroid hormones, hemispheric specialization, or laterality correlates are found, the relationships are typically weak. Studies aiming to find the basis of sex differences in cognitive abilities have produced some intriguing clues but no definitive answers.

One can imagine the great Belgian detective, Hercule Poirot, after thoroughly examining the findings in this area, looking up and softly commenting "Non, mon ami, not even Hercule Poirot can solve this mystery from such uncongenial clues—I fear, Captain Hastings, we shall have to investigate *much* further."

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